Innovations

Rock 'n' Roll Refrigerator

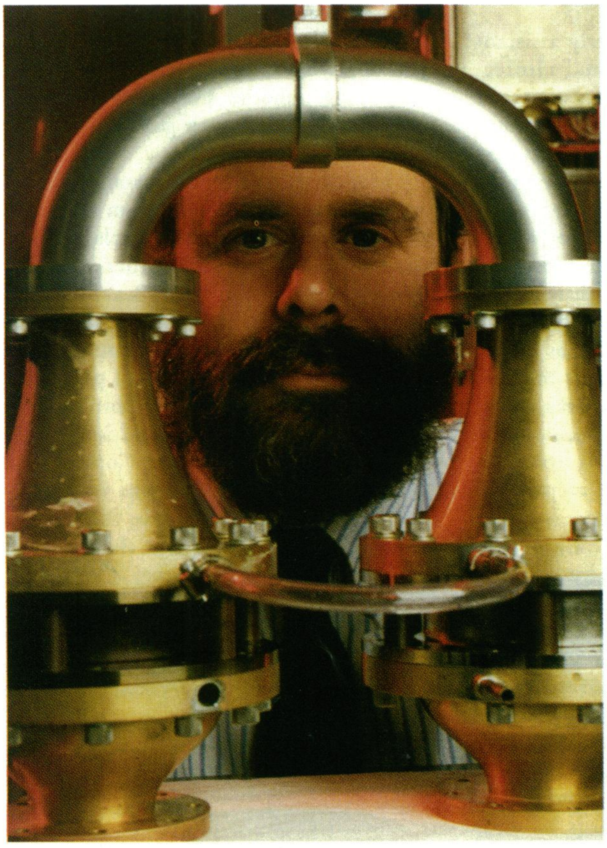
Someday, household refrigerators and air conditioners might be powered by loudspeakers blasting sound thousands of times more intense than the Rolling Stones in concert.

"Thermoacoustic" refrigerators now under development use sound waves strong enough to make your hair catch fire, inventor Steven L. Garrett notes. But don't worry—the noise is safely contained in a pressurized tube. If the tube shattered, the noise would instantly dissipate to harmless levels. Because it conducts heat, such intense acoustic power is a clean, dependable replacement for cooling systems that use ozone-destroying chlorofluorocarbons (CFCs), which will be banned after 31 December 1995, says Garrett, a physics professor at the Naval Postgraduate School in Monterey, California.

Already, Garrett and NPS Research Assistant Professor Tom Hofler have developed a thermoacoustic refrigerator offering 200 watts of cooling power—a level comparable to existing CFC-based refrigerators. Their "rock 'n' roll refrigerator" is cold enough to freeze ice or "simply keep beer chilled."

Hofler is also developing supercold "cryocoolers" capable of temperatures as low as -135°F (180°K). He hopes to achieve -243°F (120°K) because such cryogenic temperatures would keep electronic components cool in space or speed the function of new microprocessors.

Skeptics say current thermoacoustic designs are inefficient compared to conventional refrigeration systems. But Garrett continues to improve his invention, which requires only one moving part in the form of a loudspeaker and therefore may be more dependable than CFC-type refrigerators. It's also more environmentally friendly, promising a route to "leap-frog over this whole chemical dependency problem," says Garrett, a 1993 winner of the Rolex Foundation awards for enterprise in the applied sciences and invention, exploration, and discovery in the environment.



Associated Press

Mr. Cool. Researcher Steven Garrett looks through the resonator section of TALSR.

A Simple Design

How does it work? First, customized loudspeakers are attached to cylindrical chambers filled with inert, pressurized gases such as xenon and helium. At the opposite end of the tubes are tightly wound "jelly rolls" made of plastic film glued to ordinary fishing line. When the loudspeakers blast sound at 180 decibels, an acoustic wave resonates in the chambers. As gas molecules begin dancing frantically in response to the sound, they are compressed and heated, with temperatures reaching a peak at the thickest point of the acoustic wave. That's where the superhot gas molecules crash into the plastic rolls. After transferring their heat to the stack, the sound wave causes the molecules to expand and cool. "Each one of these oscillating molecules acts as a member of a 'bucket brigade,' carrying heat toward the source of the sound," says Garrett. Cold temperatures can then be tapped for chilling refrigerators, bedrooms, cars, or electronic components on satellites and inside computers, according to Garrett. Someday, he says, turning up the air-conditioner could be accomplished by adjusting a volume-control knob.

In contrast, inside conventional refrigerators and air conditioners, CFC gas is compressed and heated by an electrically driven pump, then cooled and condensed by a heat exchanger in a process known as a "Rankine cycle." When the liquefied gas is depressurized, it evaporates and drops to a much cooler temperature. Moving through the freezer coils of a food compartment, the cold fluid picks up heat, starting the cycle all over again.

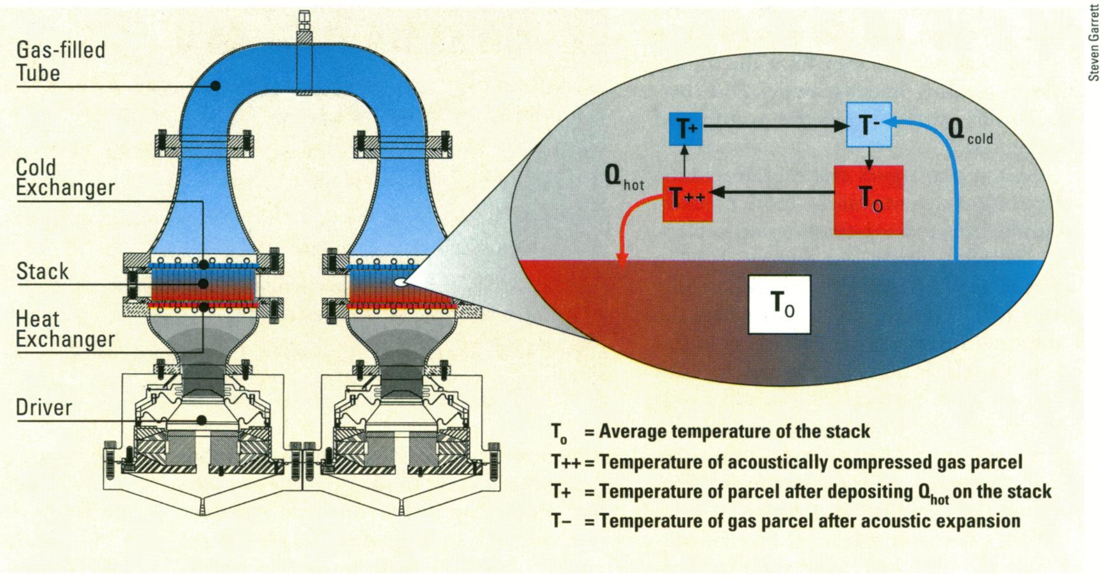
Before World War II, ammonia and sulfur dioxide were commonly used in refrigerators, explains Gregory W. Swift, a thermoacoustics expert at Los Alamos National Laboratory in New Mexico. But these substances were soon replaced with CFCs, which are noncorrosive, nonflammable, and relatively nontoxic, Swift says. Unfortunately, he adds, CFCs leak from cooling systems, destroying the atmospheric ozone that protects the earth's surface from ultraviolet radiation. Damage to the ozone shield may result in adverse human health effects including cancers, cataracts, immune system deficits, and respiratory effects, as well as diminish food supplies and promote increases in vector-borne diseases.

The Sound–Heat Connection

The relationship between sound and heat was recognized more than 100 years ago, when glassblowers heard the tone generated by a hot glass bulb attached to a cool tube, Swift says. Thermoacoustic devices simply reverse this phenomenon, using sound to move heat.

As part of his doctoral thesis for the University of California at San Diego, Hofler used thermoacoustics to make a simple yet surprisingly powerful heat-moving tube under the direction of the late John C. Wheatley and others at Los Alamos. In 1986, Hofler joined the NPS faculty and helped Garrett's research team design the "Space ThermoAcoustic Refrigerator" (STAR), a fully autonomous device weighing less than 200 pounds. Launched on the Space Shuttle Discovery in January 1992, STAR demonstrated the feasibility of thermoacoustic refrigerators. But it provided only 5 watts of cooling power, and therefore fell far short of the power requirements for household refrigerators.

Since STAR's debut, Garrett reported at the February meeting of the American Association for the Advancement of Science that NPS researchers have increased the cooling power of their original design by a factor of 40, making it feasible for use in full-scale refrigerators. Dubbed "TALSR" for ThermoAcoustic Life Sciences Refrigerator, STAR's successor was originally designed to keep biological samples cool in space, where zero-gravity creates problems such as the migration of lubricants inside vapor-compression refrigerators.



Bucket brigade. A gas parcel is compressed and heated by the sound wave and deposits some of its heat to the stack. The sound wave then expands and cools the gas parcel so that the gas can absorb heat from the stack and cool it. The parcels absorb heat from the cold exchanger and pass it along the stack.

When the National Aeronautics and Space Administration withdrew its support for TALSR because of a funding shortage, Garrett jokingly renamed his invention HOTAR, for "Homeless Orphan ThermoAcoustic Refrigerator." The U.S. Navy is now funding TALSR as a method for cooling shipboard electronics. Meanwhile, Garrett hopes a third design not yet unveiled will provide another factor of 40 increase in cooling power—enough for air-conditioning systems.

A handful of research laboratories and major corporations, including Ford Motor Company and Modine Manufacturing of Racine, Wisconsin, have now joined Garrett in developing thermoacoustic refrigeration systems. At Ford's Scientific Research Lab, research scientist George Mozurkewich continues to study thermoacoustics, though he says it probably won't be useful for car air-conditioning systems anytime soon. Car air-conditioning units require at least 5000 watts of cooling power, and existing thermoacoustic designs provide only 200 watts, he notes. Current thermoacoustic systems are also too bulky and heavy for car air conditioning, he says. Still, thermoacoustic refrigeration may prove useful for "niche applications," such as cooling satellite sensors or super-fast computers, Mozurkewich adds.

Peavey Electronics of Meridian, Mississippi, and Cardinal Research Corporation of Richmond, Virginia, hope to use Garrett's patented design in thermoacoustic refrigerators for fishing boats and other marine vessels. Refrigerating the day's catch or keeping a yacht cool has always been problematic, explains Cardinal President Jeremy Crews. Conventional refrigerators require a 120-volt alternating current, which must be generated at sea by an on-board diesel power plant. Unfortunately, Crews says, diesel generators tend to be noisy, smelly, and unreliable. A battery-powered thermoacoustic refrigerator might be suitable for use on commercial or pleasure vessels, he adds. Thermoacoustic air conditioning systems for homes and office buildings are planned by Cool Sound Industries of Port St. Lucie, Florida. CSI President Frank Wighard says the technology "could be brought to market in less than 2 years with the proper funding."

In rural Bangladesh, where electricity is scarce and ice must be hauled long distances, researchers are developing simple kerosene-driven thermoacoustic refrigerators to keep life-saving medical supplies cool. And at Los Alamos, Swift's team is collaborating with Ray Radebaugh of the National Institute of Standards and Technology and Tektronix Corporation to develop coolers based on pulse-tube technology for electronic components. A technological cousin of thermoacoustic refrigerators, pulse-tube coolers use a traveling acoustic wave (instead of a standing wave) and offer greater efficiency at lower temperatures. Los Alamos researchers are also working with Radebaugh and Cryenco Company to make pulse-tube coolers that liquefy natural gas at derelict well sites, perhaps for use in fleet vehicles.

Technical Challenges

Because they use low-cost components and require only one moving part, Garrett's refrigerator could lead to inexpensive, maintenance-free systems that don't destroy the ozone. But researchers must overcome a number of technical challenges. The efficiency of thermoacoustic refrigerators, for instance, has repeatedly been called into question.

Since they use electricity to drive a pump that moves working gas, conventional refrigerators represent 6% of the nation's annual electricity consumption, Swift notes. Similarly, the loudspeakers inside a thermoacoustic refrigerator also must be activated by electrical power. Swift says the best thermoacoustic coolers built thus far use "twice as much electricity as conventional refrigerators." Though much greater efficiency is theoretically possible, Swift doubts that thermoacoustic refrigerators will ever catch up with traditional Rankine-cycle designs.

Complex physical factors such as the friction generated by gas molecules churning back and forth inside a chamber place fundamental limits on the efficiency of thermoacoustic refrigerators, according to Swift. Losses also occur because of acoustic distortions generated at levels above 155 decibels, says Rick Weisman, vice president of applied technologies at the Harman International Acoustics Company of Northridge, California. "We can't afford to replace the old CFC-based technology with one that's less efficient, because then we're using more fossil fuels to run those devices," Swift says.

But Garrett points out that thermoacoustic technologies still have plenty of room to grow. "Year after year, improvements are made and breakthroughs are achieved," he says. Unfortunately, he adds, progress has been stymied by a lack of support from the U.S. refrigeration industry, which is focusing on chemical CFC substitutes. "The vapor-compression guys are doing very well, and they're going to be hard to beat because they have the money to keep pushing improvements. But thermoacoustic technologies are young and moving fast."

Garrett also argues that thermoacoustic refrigeration systems can be more precisely controlled than vapor-compression coolers, and therefore waste less energy. With a conventional refrigerator, "it's either fully on or off," Garrett says. "So, when the thermostat turns it on, it gets too cold and when it is off, it heats up too much. With an acoustic refrigerator, it's much like your home stereo. It's got a volume control so it can be set by the thermostat to precisely the appropriate level for the required temperature and heat load at all times."

Ford's Mozurkewich says the efficiency of electric-to-acoustic conversion in thermoacoustic refrigerators "isn't particularly good." Yet, he admires Garrett's "unsuppressible enthusiasm," and points out that NPS researchers have already made significant design improvements. Garrett's collaborator at Peavey Electronics, Mike O'Neill, director of transducer engineering, says the efficiency of thermoacoustic refrigerators might not be so critical for certain niche applications such as space cooling.

The Search for CFC Replacements

The nation's largest CFC manufacturer, the DuPont company of Wilmington, Delaware, has invested nearly $500 million in CFC alternatives thus far, reports staffer Sharon Gidumal, an environmental specialist. Much of the research has emphasized chemical CFC substitutes such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs).

"We are focusing mainly on chemical compounds to replace CFCs," Gidumal says. "Our goal was to minimize economic disruption and develop compounds that perform as closely to the originals as possible." According to DuPont, CFC production employs an estimated 700,000 workers at 5,000 American businesses worth $28 billion. Complete retooling of existing vapor-compression equipment and factories would have dire economic consequences, Gidumal notes.

Unfortunately, the safety of HCFCs has been questioned. Although they're believed to decompose before reaching ozone altitudes, HCFCs clearly destroy ozone, Hofler says. Consequently, HCFCs will be banned in developed countries by the year 2030 in keeping with the Montreal Protocol, an international treaty.

A DuPont spokeswoman says HFCs, which contain no chlorine and therefore don't destroy ozone, appear to be a safe, viable alternative to CFCs. Swift and some environmentalists aren't completely convinced. "[HFCs] are, as far as everyone knows, perfectly safe in terms of their interaction with stratospheric ozone," Swift says. "However, they are greenhouse gases. Whether or not the greenhouse gases are a problem is still a matter of debate. But some people wouldn't be surprised if [HFCs] are eventually regulated."

Swift believes that propane and butane are far more feasible as replacements for CFCs inside vapor-compression refrigerators. These hydrocarbons are highly flammable, but he claims they could be used safely and would offer greater efficiency than thermoacoustic refrigerators. Carbon dioxide is also being studied as an environmentally benign substitute for CFCs.

Despite his skepticism about the efficiency of thermoacoustic refrigerators, Swift respects Garrett's determination. "If the optimistic point of view is right," Swift says, "then the scientists that think about these things might come up with something new to improve efficiency. Who knows?"

Garrett, meanwhile, is doggedly pursuing his dream of a thermoacoustic future. "Ultimately, the answer is going to be given in the basement of Sears in the year 2000," he says. "I'm certainly not reducing my efforts."

Ginger Pinholster

Ginger Pinholster is a freelance writer in Wilmington, Delaware.

Suggested Reading

Acoustical heat pumping engine. U.S. patent no. 4,398,398. Washington, DC:U.S. Patents Office, 16 August 1983.

Garrett S. Thermoacoustic life sciences refrigerator. NASA technical report no. LS-10114. Houston, TX:Johnson Space Center, 1991.

Garrett SI, Adeff JA, Hofler TJ. Thermoacoustic refrigeration for space applications. J Thermophys Heat Transfer 7(3): (1993).

Intrinsically irreversible heat engine. U.S. patent no. 4,489,553. Washington, DC:U.S. Patents Office, 25 December 1984.

Swift GW. Thermoacoustic engines. J Acoust Soc Am 84:1145–1180 (1988).